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FEDERAL COMMUNICATIONS COMMISSION
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**Before the**
**FEDERAL COMMUNICATIONS COMMISSION**
**Washington, D.C. 20554**

ORIGINAL FILE

| | | |
|---|---|---|
| | ) | GEN Docket No. 90-314 |
| | ) | ET Docket No. 92-100 |
| In the Matter of | ) | |
| | ) | RM-7140, RM-7175, RM-7617 |
| | ) | RM-7618, RM-7760, RM-7782, |
| Amendment of the Commission's | ) | RM-7860, RM-7977, RM-7978 |
| Rules to Establish New Personal | ) | RM-7979, RM-7980 |
| Communications Services | ) | |
| | ) | PP-35 through PP-40, PP-79 |
| | ) | through PP-85 |

**COMMENTS OF PCN AMERICA**

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November 9, 1992

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**SUMMARY**

PCN America filed Comments on October 20, 1992, herein urging the Commission to adopt a licensing structure for PCS providing for three categories of PCS licensees. This filing addresses remaining issues in the Commission's NPRM.

PCN America urges the Commission to provide 40 MHz of spectrum (in two 20 MHz blocks) for each PCS licensee and to award two PCS licenses per market in each license tier. A 20 MHz allocation should be made for unlicensed services and the remaining 40 MHz should be maintained in reserve for growth and for new technologies. The proposed 10 MHz allocation for fixed wireline local loop services, while needed, should be located in other spectrum. Entities in addition to local exchange telephone companies should be eligible for these licenses. To maximize competition in PCS services, cellular carriers and local telephone companies should not be awarded PCS licenses in their existing service territories. Finally, PCN America urges the Commission to alter its proposed PCS interference criteria and to provide for a variety of interference protection techniques including space, angle, and frequency diversity.

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To: The Commission

## COMMENTS OF PCN AMERICA

PCN America, Inc., a subsidiary of Millicom Incorporated, referred to herein as "PCNA" or "Millicom," hereby submits comments on the Commission's Notice of Proposed Rulemaking and Tentative Decision concerning Personal Communication Services ("PCS")[1] PCN America filed a licensing proposal[2] in response to the NPRM on October 20, 1992 (attached hereto) in order to provide an opportunity for interested parties to comment in this pleading round. PCN America's comments below address the remaining issues raised in the NPRM.

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[1] Amendment of the Commission's Rules to Establish New Personal Communications Services, FCC Gen. Docket No. 90-314, ET Docket No. 92-100, FCC 92-333, released August 14, 1992 ("NPRM").

[2] Licensing Proposal of PCN America, Inc. filed October 20, 1992.

## PCS SPECTRUM REQUIREMENT

The Commission proposed a "Preferred option" of 30 MHz to be assigned to each new PCS licensee. That 30 MHz would be divided into two 15 MHz blocks separated by 80 MHz.[3] The Commission also requested comment on whether 20 or 40 MHz would be a better option for PCS service.[4]

Telocator, in its Spectrum Estimates for PCS Report, provides an estimate of spectrum requirements based on projected traffic demands for PCS.[5] The report shows that PCS implementation using current technology to meet user requirements for voice quality and data rates [6] along with an optimistic cell deployment scheme will require at least 84 MHz for a single provider, 49 MHz each for two providers or

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3 The 80 MHz separation for PCS was chosen because of the channelization structure of the 2 GHz point-to-point microwave band. While the Commission's efforts to fit PCS into the 80 MHz channelization scheme are laudable, in fact that structure may not be followed in a large percentage of microwave licenses. In Chicago, only 39 of the 76 hops utilize 80 MHz paired frequencies. Since this is just over half the assignments, the benefits of 80 MHz paired frequencies may not be as great as had been anticipated, and may not outweigh the advantages of contiguous frequencies that allow Time Division Duplexing ("TDD"). "FAZE" Document prepared by Ameritech, September 18,1992, Telocator # TE/92-9-18/137.

4 See NPRM at 16 para. 36.

5 See Telocator Spectrum Estimates for PCS Report (the "Spectrum Report") - TE/92-5-28/076

6 "Voice quality approaching wireline..., the need to carry voice band data up to 4800 baud delivered by traditional wireline voice modems, the need to transport facsimile, and a requirement for low cost subscriber and infrastructure equipment consistent with reasonably long battery life will drive the technology selection towards 32 Kbps initially with migration towards 16 Kbps voice coding." Spectrum Report at 5.

36 MHz each for three providers.[7] These estimates were for clear spectrum and should be expanded since PCS will share spectrum with point-to-point microwave services. These spectrum estimates were calculated based upon voice traffic only. Traffic densities for data were not included and would serve to increase the amount of spectrum required to deliver PCS. Based on these estimates, the current preferred option of 30 MHz will be insufficient to provide enough capacity for all the services required by the PCS end user.

In addition, the allocation of 30 MHz per licensee gives rise to split allocations of 15 MHz in two frequency blocks. The current channelization scheme for 2 GHz microwave (10 MHz and a few 5 MHz channels) suggests that a new PCS provider will potentially be forced to coordinate or negotiate with two microwave users occupying 40 MHz of spectrum while only being allowed to use 30 MHz for its services.[8]

An allocation of 40 MHz, split into two 20 MHz blocks, would more closely match the spectrum needs estimate of industry groups like Telocator and would simplify the coordination or relocation process with regard to microwave users. PCN America, therefore, proposes two allocations of 40 MHz each for PCS in the 1850-

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[7] The questionable viability of three PCS licenses per market and the PCNA proposal for two providers is addressed elsewhere in these comments.

[8] A PCS provider assigned Block A (1850-1865/1930-1945 MHz) would have to negotiate with microwave users occupying 1850-1860/1930-1940 MHz **and** 1860-1870/1940-1950 MHz in order to make effective use of all allocated spectrum. This would require the PCS provider to pay coordination or relocation expenses for 10 MHz of spectrum for which it received no benefit.

1990 MHz band. The allocations would be split into two 20 MHz blocks separated by 80 MHz. The remainder of the 1850-1990 MHz band would be allocated as follows:

20 MHz (1910-1930 MHz) for non-licensed PCS, and

40 MHz (1890-1910/1970-1990 MHz held in reserve for additional capacity or new technologies.

The block allocations proposed in the NPRM are based on dividing the available spectrum into three frequency block pairs per geographic area.[9] The economic viability, competitiveness and feasibility of three PCS licenses is discussed below.

**NUMBER OF LICENSES**

The Commission stated that its goal is to provide an allocation that allows for the provision of the widest range of PCS services at the lowest cost to the consumer. The most desirable allocation to accomplish this goal would be one large enough to accommodate all entities interested in providing PCS services." The NPRM "...tentatively conclude[d] that an allocation that provides sufficient spectrum to support at a minimum three service providers per market will be necessary to ensure a wide and rich range of PCS services that will meet consumer needs at reasonable prices".[10]

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[9] See NPRM at 16 para. 38.

[10] See NPRM at 15 para. 34.

The Commission, in its desire to create sufficient licensing opportunities to accommodate as many entities as possible, may not have focused on the impact of this choice on the financial viability of PCS providers. Currently, in almost every market, there are at least nine companies or categories of companies who provide or will provide some form of PCS services through wireless means or through the provision of database driven services such as the Universal Personal Number. These include the local exchange carrier, the two cellular providers, the three dominant interexchange carriers, wireless data services and multiple paging and SMR providers. This structure means that a new PCS entrant in almost any market will have as many as nine competitors already in place with an existing infrastructure and customer base. While the Commission clearly intends to create a strong and economically viable PCS industry the licensing of three service providers may interfere with this objective.

While one new PCS provider in each market would be the most economically viable, this option would also provide the least additional competition. The best overall option would, therefore, be to license two new PCS entrants in each market. This option would provide for significant competition for all aspects of personal communication (e.g., the provision of UPT by the IXCs, the ability to notify a subscriber of an incoming message by paging, etc.) and should fulfill the Commission's desire to meet consumer needs at a reasonable price. By limiting the number of new entrants to two, the Commission would create an environment where it should be possible for PCS providers to remain financially sound. This should also contribute to better service at lower cost to the consumer.

## LEC PARTICIPATION

Local Exchange Carriers (LECs) should be allowed to participate in PCS only in areas where they currently do not offer wireline service. PCS will provide needed competition for LEC Services. Permitting a local exchange carrier to acquire a PCS license would substantially diminish this competitive potential. In addition, cross subsidization and interconnect discrimination could place PCS providers at a serious competitive disadvantage. If the LECs are allowed to provide PCS service within their wireline service areas then a variety of regulatory safeguards will be needed. Administering these safeguards will lead to numerous regulatory proceedings. The LECs should bring their experience and capabilities to bear by providing PCS in areas where they presently do not offer wireline service.

Revenue derived from the provision of network services to PCS operators should provide an incentive for the LECs to develop a PCS-friendly wireline architecture. If the LECs prove slow to provide these services, recent efforts by the Commission to spur competition in the local loop will help ensure that network services will be provided by a LEC competitor (i.e., Cable, Competitive Access Providers, etc.)

## 10 MHz ALLOCATION

To achieve the economies of scope desired from the combination of LEC wireline and wireless services, PCN America proposes that the FCC allocate spectrum for fixed services in frequencies other than the 1850 - 1990 MHz band which has been allocated for mobile uses. It would clearly serve the public interest to promote the development of "wireless tails" which would extend the reach of the wireline network. If spectrum is granted for these services it should be made available not only to the LECs but also to potential competitors.

**CELLULAR PARTICIPATION**

The commission has made clear its desire that cellular and PCS providers "compete on price and quality."[11] To achieve this objective cellular operators should be excluded from spectrum allocations or acquisitions within any PCS licensing region where they currently serve more than ten percent of the subscribers. This would ensure that the new PCS frequency allocations are made available to competing service providers rather than being absorbed by existing entities. The ten percent benchmark limits any needlessly stringent exclusion which could arise because cellular and PCS licensing areas are different.

Licensing cellular carriers to provide PCS in their cellular service areas would upset the competitive balance among service providers. If the cellular companies receive spectrum at 1850 MHz within their cellular service area, new PCS entrants without cellular frequencies will be at a distinct competitive disadvantage. Stand alone cellular and PCS providers would find it difficult to compete with combined cellular/PCS carriers which would enjoy:

(i) the existence of current infrastructure, billing mechanisms and subscribers;

(ii) the ability to offer their subscribers dual mode or single mode units which operate at 800 MHz, 2 GHz or a combination of the two;

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[11] NPRM at 26.

(iii) 25 MHz more spectrum than the other PCS operators; and

(iv) more spectrum than the other cellular operator in the region.

## PCS-MICROWAVE INTERFERENCE CRITERIA

In the NPRM, the FCC indicated that "We believe that the level of protection provided under our rules [47 C.F.R. § 94.63] and through the use of TSB-10E is appropriate and propose, in general, to provide the microwave users with this same level of protection for interference from PCS operations."[12] PCN America disagrees with this conclusion for the following reasons.

First, PCN America believes that the EIA 10-E criteria are much too conservative for use in today's crowded spectrum environment. They afford all microwave systems the same protection, on an absolute basis, independent of the most important microwave system design consideration: reliability. The EIA-10E standard as it is currently written does not quantitatively address the reliability of a microwave system, but rather imposes a 1 dB limitation to preserve whatever reliability a system is currently designed for. Because of this, the majority of microwave systems today are *over-engineered* with huge fade margins, and resulting reliabilities on the order of seconds per year. Clearly, in the interest of spectral efficiency, microwave system protection requirements should be based upon a standard reliability figure to facilitate co-existence with low-power mobile systems in the same frequency band. In addition, techniques, such as space, angle and frequency diversity, can further improve microwave system reliability. The improvement factors resulting from

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[12] NPRM at 44.

implementation of these techniques are quite significant, and are not currently taken into account in TSB-10E. PCN America believes that TSB-10E must be revised. Recommendations for TSB-10E revision are described in detail in Appendix I. Additional coordination issues raised in the PCS NPRM are addressed below.

**PCS Power Aggregation** - TSB-10E states on page 7 "No matter how complex a total interference analysis may be, it always treats some number of individual potential exposures, each of which must be resolved *independently*. Each exposure involves one transmitter and one receiver, and the question to be answered is 'Does this transmitter interfere with this receiver?'". In Appendix F of the PCS NPRM, the FCC recommends that the interference from all sources (mobiles *and* base stations) be summed at the microwave receiver, assuming straight power addition. This recommendation contradicts the intention of TSB-10E and imposes much stricter interference criteria on the PCS operator. If an aggregate interference analysis is to be required of the PCS transmitters, it should also be required of the microwave transmitters. Therefore, unless TSB-10E is applied on a base station-by-base station, or user-by-user basis, it should not be applicable to PCN interference considerations.

**PCS Power and Antenna Height Limits** - To maximize spectrum sharing, PCS power limitations must be considerably lower than cellular limits. Limits suggested in the NPRM (10 Watts EIRP and 300 feet antenna height) for the base station are reasonable for spectrum sharing. This would allow for adequate PCS cell coverage areas while still maintaining power levels low enough for microwave coexistence.

**Coordination Distance** - In the NPRM, the commission indicated "we would require parties desiring to implement PCS operations to demonstrate protection to all co-channel and adjacent channel microwave receivers within 201 km (125 mi) of any PCS base station."[13] PCN America disagrees with this proposal because:

a.) It implicitly requires coordination over distances which are beyond line-of-sight, and

b.) It does not take into account the various antenna heights which may be used for the base stations.

PCN America urges the commission to specify coordination distances on a case-by-case basis, taking into account the proposed base station antenna height and actual microwave antenna height to determine the coordination zone for each base station. This will result in a considerable savings in coordination time and effort for the PCS provider, while still affording microwave receivers adequate protection.

**Outdoor Propagation** - PCN America believes that imposing free-space propagation constraints for base station/microwave coordination will provide microwave users with more protection than is required, and therefore result in an inefficient utilization of shared spectrum. Use of a modelling technique which takes into account actual terrain and obstructions in the interfering path (such as TIREM) would be far more accurate. In situations where the necessary data are unavailable, a statistical approach (Hata or otherwise) would be vastly more accurate than a free space model.

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[13] NPRM at 46.

**Building Loss** - PCN America agrees with the Commission's statement in Appendix F of the NPRM that "...the equivalent portable EIRP should be weighted according to the estimated portion of portables expected to be operated inside buildings at any given time..." Once an estimate is made as to the percentage of users located in-building in a cell (PCN America believes that typically 80% of the users in an urban area will be indoor users), the loss *from each floor* to the outside of the building should be calculated based on the discrimination angle between the floor height and the microwave receiver antenna height.

Recommendations for PCS/Microwave coordination appear in Appendix I, together with an in-depth analysis of the points raised above. PCN America believes these recommendations to be crucial to insure successful and efficient spectrum sharing between PCS providers and OFS microwave users.

Respectfully submitted,

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# 1 Appendix I: PCS-Microwave Interference Criteria

## 1.1 Applicability of TSB-10E Interference Criteria

In para. 110 of the PCS NPRM, the FCC states "We believe that the level of protection provided under our rules [47 C.F.R. § 94.63] and through the use of TSB-10E is appropriate and propose, in general, to provide the microwave users with this same level of protection for interference from PCS operations." PCN America disagrees with this conclusion for the reasons described in the following paragraphs.

Telecommunications Systems Bulletin 10-E (*"TSB 10-E"*) was initially published by the Electronic Industries Association (*"EIA"*) in conjunction with the Telecommunications Industry Association (*"TIA"*) in July of 1972 in order to "provide methodology and criteria for properly coordinating microwave radio systems in the Private Radio Services"[1]. The criteria are based on interference established in Part 94 of the FCC rules and regulations. Endorsed by the Operational Fixed Microwave Council (*"OFMC"*), the bulletin has been updated several times since 1972, with the latest revision, TSB-10E, being released in December, 1990.

PCN America, in its Amendment to its experimental license application[2], stated that all interference test results "... will employ interference standards specified in [TSB 10-D] ... taking into consideration reasonable and customary frequency coordination procedures...". To date, PCN America has conducted all interference testing and simulations in accordance with this standard.

After almost two years of testing and analysis, PCN America has become increasingly aware of the inappropriateness of this standard in the context of PCN-Microwave frequency sharing.

TSB-10E sets forth defined interference criteria for both analog (FM-FDM) and Digital microwave systems. **For analog systems**, PCN America, in conjunction with the Houston Area Microwave User Group (*"HAMUG"*) and the Orlando Microwave User Group (*"OMUG"*), has employed a threshold degradation limitation of 1 dB for PCN interference (e.g. PCN interference cannot increase the noise floor by more than 1 dB). This corresponds to an interference level roughly *6 dB below the thermal noise floor* of the microwave receiver.

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[1] "Telecommunications Systems Bulletin 10-E, Rev. D", Telecommunications Industry Association, August 3, 1992, p.6.

[2] "Amendment to Application for Authorization in the Experimental Radio Service of a Spread Spectrum Personal Communications Network", PCN America,Inc., April 23, 1991.

Theoretically, assuming that the PCN center frequency and the microwave center frequency coincide, the maximum allowable interference level from a CDMA spread spectrum interferer can be calculated as follows:

$$
\begin{aligned}
I_{max} &= N_{thermal} + 10\log(B_{PCN}/B_{\mu W}) + N_{1dB} \\
&= 10\log(kTB_{\mu W}) + NF + C_{dBm/dBw} + 10\log(BW_{PCN}/BW_{\mu W}) - 10\log(0.25) \\
&= 10\log[(1.38 \times 10^{-23})(300)(7 \times 10^{6})] + 5 + 30 + 10\log(28/7) - 6 \\
&= \mathbf{-100.3\ dBm}
\end{aligned}
$$

where

| | | |
|---|---|---|
| $N_{thermal}$ | = | Thermal Noise of the microwave receiver |
| $B_{PCN}$ | = | The half-power bandwidth, in MHz, of the PCN CDMA system |
| $B_{\mu W}$ | = | The half-power bandwidth, in MHz, of a typical 10 MHz microwave receiver |
| $N_{1dB}$ | = | The TSB-10E incremental noise allowance |
| k | = | Boltzman's Constant |
| T | = | Temperature, in degrees Kelvin |
| NF | = | The noise figure of a high performance microwave receiver |
| $C_{dBm/dBw}$ | = | The conversion factor from dBw to dBm |

This figure, equivalent to *0.1 nW*, was employed in the Comsearch Cell-Site Deployment Plan developed for PCN America. Note that this analysis holds true for 5 MHz microwave receivers also, as the reduced microwave bandwidth (and hence the reduced thermal noise level) is compensated for by the increased spread spectrum "gain" -- $BW_{PCN}/BW_{\mu W}$. These results correspond closely to the in-field measurements taken in April and May in Houston and Orlando[3].

Where the PCN and microwave frequencies did not coincide, offset factors, based on the CDMA spectral distribution, were used.

**For digital systems**, "...the effect of interference...is primarily one of threshold degradation..."[4]. Specifically, the threshold-to-interference ratio (*"T/I"*) was used to determine the acceptable PCN interference level into the microwave receiver. The T/I ratio is defined as "...the ratio of desired to undesired signal that degrades performance from $10^{-6}$ to $10^{-5}$ Bit-Error-Rate (*"BER"*)."[5]

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[3] "Results of Field Trials Held in Houston, Texas and Orlando, Florida", PCN America, Inc., June 14, 1991.

[4] "Telecommunications Systems Bulletin 10-E, Rev. D", Telecommunications Industry Association, August 3, 1992, p.24.

[5] Ibid, p.52

Typically, the T/I ratio will fall between 20 and 35 dB, with the threshold level -70 to -80 dBm. The resulting interference power limit is comparable to the analog case discussed above, and therefore the same received power limitations (including frequency offsets) can be used as an estimate for digital receivers.

PCN America believes that these interference criteria are much too conservative for use in today's crowded spectrum environment. They afford all microwave systems the same protection, on an absolute basis, independent of the most important microwave system design consideration : **reliability**.

*The reliability of a microwave system is perhaps the most important design consideration to the microwave engineer.* Many factors affect system reliability including[6]:

1.) Equipment Failure Rates
2.) Power Failures
3.) System Noise
    a.) Thermal Noise
    b.) Intermodulation Noise
    c.) Echo Distortion Noise
    d.) Multiplex System Noise
4.) Atmospheric Effects
5.) Delay Distortion
6.) Multipath Fading

PCN interference does not affect system reliability with regard to items (1), (2) and (3) -- these are dependent on equipment design. Consideration (5) can be equipment related or related to path selection, and (4) has little or no effect at 2 GHz. The only reliability factor which PCN interference will effect is (6): multipath fading.

The effects of multipath fading on system reliability can be described as follows:

> The Rayleigh distribution is often taken as the limiting value for multipath fading on line-of-sight paths with adequate clearance. One way of estimating reliability is to make a *"worst case"* assumption that a path will have continuous Rayleigh-distributed fading. This distribution has a slope of 10 dB per decade of percentage of time. A path with this fading distribution would have 20 dB fades for 1% of the time, 30 dB fades for 0.1% of the time, and 40 dB fades for 0.01% of the time. Continuous Rayleigh-distributed fading is *unlikely* to occur on most paths, and the assumption is therefore very much on the *conservative side*.[7]

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[6] Engineering Considerations for Microwave Communications Systems. AG Communication Systems, 1989, p.66.

[7] Ibid, p.54.

In the Houston area, the average *fade margin* of all the receivers is on the order of 45 dB. From the above worst-case estimation, this means that the average receiver will be faded to threshold 0.005% of the time, or about 4 seconds per day.

The most widely-accepted method for estimating outage probability (and therefore reliability) due to fading was developed by W.T. Barnett and Arvids Vagnats, of Bell Telephone Laboratories[8]

The resulting formula assumes non-diversity reception:

$$U_{ndp} = a \times b \times 2.5 \times 10^{-6} \times f \times D^3 \times 10^{-F/10}$$

where

- a = terrain factor (4 → smooth, 1 → average, 1/4 → mountainous)
- b = humidity factor (1/2 → humid, 1/4 → temperate, ⅛ → dry)
- f = frequency (GHz)
- D = Path Length (miles)
- F = Fade Margin (dB)

$U_{ndp}$ can be translated into reliability ($1 - U_{ndp}$) or into annual outage time (31,536,000 sec/yr $\times U_{ndp}$). Table 1 and Figure 1 illustrate the annual non-diversity outage times for 47 microwave receivers in the Houston area. The annual outage times vary from a maximum of 142 seconds to a minimum of 0.0009 seconds, with an average annual outage time of **25 seconds/yr**.

TSB-10E is the standard for microwave frequency coordination in the fixed service microwave industry. It has been revised over the years to include new applications, including various digital and video fixed service offerings. However, it was *never intended to be used for co-existence with mobile services*. Even in its latest revision (Rev 10E-D, dated 8/3/92), mobile interferers are not mentioned.

## 1.2 <u>Alternatives for PCN-Microwave Coexistence</u>

### 1.2.1 Current Microwave Systems are Over-Engineered

The TSB-10E standard as it is currently written does not quantitatively address the reliability of a microwave system, but rather imposes a 1 dB limitation to preserve whatever reliability a system is currently designed for. Because of this, the majority of microwave systems today are *over-engineered* with huge fade margins, and resulting reliabilities on the order of seconds per year. Clearly, in the interest of spectral efficiency, all microwave system protection requirements should be based

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8 Ibid, p.60.

upon a standard reliability figure to facilitate co-existence with a low-power mobile systems in the same frequency band.

Even in the latest revision, where Section 4.5 ("Availability as Coordination Criteria") has been added, the TIA continues to skirt this issue. PCN America agrees with the view stated in this section that "A more reasonable means of determining coordination in today's congested frequency spectrum is to consider *availability* as the factor to be coordinated."[9] However, while the section later describes how to coordinate using availability as a criterion, it does not specify an availability (reliability) limitation or standard for the microwave systems.

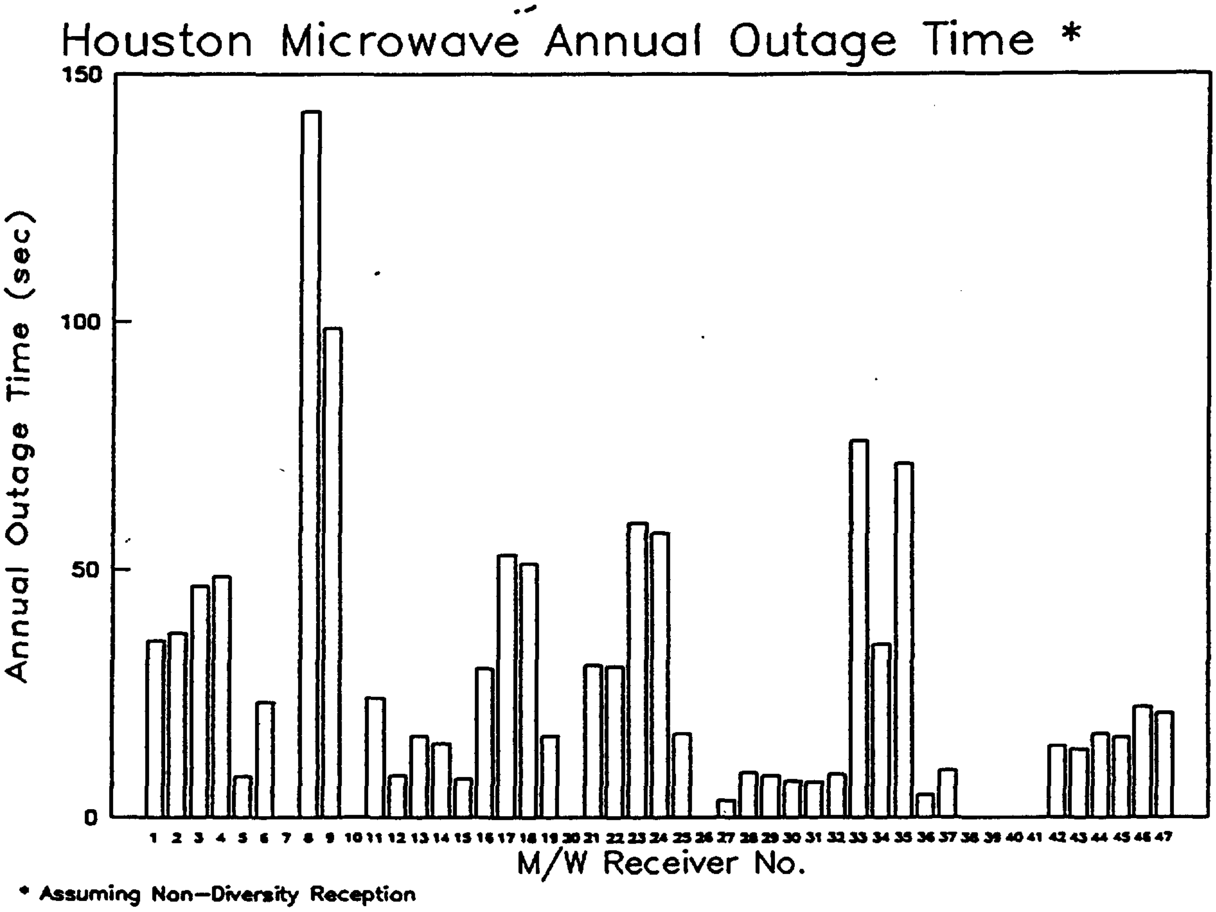


Figure 1 - Houston Annual Non-Diversity Outage Times

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[9] "Telecommunications Systems Bulletin 10-E, Rev. D", Telecommunications Industry Association, August 3, 1992, p.63A.

# Table 1 - Houston Annual Outage Times

| M/W Receiver Number | | Station Address (Transmitter) | Carrier Freq (MHz) | Path Length (mi) | Rcvr Sens (dBm) | Receive Signal Lv (dBm) | Fade Margin (dB) | * Non-Diversty Annual Outage (sec) |
|---|---|---|---|---|---|---|---|---|
| | Amoco | | 1860 | | | -40.00 | | — |
| | Amoco | | 1980 | | | -40.00 | | |
| | Amoco | | 1960 | | | | | |
| | Amoco | | 1940 | | | -40.90 | | |
| | Amoco | | 1860 | | | -40.90 | | |
| 1 | ARCO | North Houston | 1860 | 19.73 | -80.00 | -38.00 | 42.00 | 35.5313 |
| 2 | ARCO | Channelview | 1940 | 19.73 | -80.00 | -38.00 | 42.00 | 37.0595 |
| | AT & SF RR | | 1965 | 21.00 | | -37.90 | | |
| | AT & SF RR | | 1885 | 21.00 | | -34.90 | | |
| | AT & SF RR | | 1875 | 22.00 | | | | |
| 3 | Chevron | Corporate Dr. | 1885 | 6.30 | -71.00 | -45.00 | 26.00 | 46.6713 |
| 4 | Chevron | Memorial Dr. | 1965 | 6.30 | -71.00 | -45.00 | 26.00 | 48.6520 |
| | Coastal St's | | 1915 | 25.00 | | | | |
| | Coastal St's | | 1875 | 28.00 | | -42.00 | | |
| | Coastal St's | | 1955 | 28.00 | | -41.80 | | |
| | Coastal St's | | 1965 | 20.00 | | -39.00 | | |
| | Coastal St's | | 1915 | 6.00 | | -42.00 | | |
| | Coastal St's | | 1855 | 6.00 | | -42.00 | | |
| | Coastal St's | | 1865 | 20.00 | | -39.00 | | |
| | ENRON | | 1925 | 10.00 | | -33.80 | | |
| | ENRON | | 1975 | 10.00 | | -38.80 | | |
| | ENRON | | 1965 | 16.00 | | -41.40 | | |
| | ENRON | | 1915 | 16.00 | | -41.40 | | |
| | ENRON | | 1945 | 26.00 | | | | |
| | ENRON | | 1865 | 21.00 | | -41.60 | | |
| | ENRON | | 1945 | 21.00 | | -41.30 | | |
| | ENRON | | 1985 | 24.00 | | -33.30 | | |
| | ENRON | | 1885 | 24.00 | | -40.00 | | |
| 5 | Exxon | Houston | 1855 | 13.01 | -74.00 | -31.10 | 42.90 | 8.2583 |
| 6 | Exxon | Houston | 1895 | 15.89 | -74.00 | -32.90 | 41.10 | 23.2647 |
| 7 | Exxon | Houston | 1865 | 3.95 | -74.00 | -31.80 | 42.20 | 0.2730 |
| 8 | Exxon | Houston | 1885 | 23.68 | -84.00 | -45.60 | 38.40 | 142.6176 |
| 9 | Exxon | Goose Creek | 1975 | 23.68 | -84.00 | -43.80 | 40.20 | 98.7254 |
| 10 | Exxon | EPRC | 1965 | 3.95 | -74.00 | -30.80 | 43.20 | 0.2285 |
| 11 | Exxon | ECA | 1955 | 15.89 | -74.00 | -32.90 | 41.10 | 24.0013 |
| 12 | Exxon | Benmar | 1915 | 13.01 | -74.00 | -31.10 | 42.90 | 8.5254 |
| | Galveston Co. | | 1950 | | | | | |
| | Galveston Co. | | 1960 | 14.00 | | -56.00 | | |
| | Galveston Co. | | 1880 | 14.00 | | -56.00 | | |
| | Galveston Co. | | 1870 | 3.00 | | | | |
| | Galveston Co. | | 1890 | 8.00 | | -48.90 | | |
| | Galveston Co. | | 1970 | 8.00 | | -48.90 | | |
| | Houston P&L | Peters | 1865 | 13.30 | | -41.64 | | |
| | Houston P&L | Allen Creek | 1945 | 13.30 | | -47.20 | | |
| | KTRK, Inc. | | 1990 | | | | | |
| 13 | Mobil | Sealy | 1895 | 14.88 | -85.00 | -43.26 | 41.74 | 16.4867 |
| 14 | Mobil | Eagle Lake | 1975 | 14.88 | -85.00 | -42.66 | 42.34 | 14.9655 |
| 15 | Oxy, USA | Memorial Dr. | 1940 | 10.30 | -80.00 | -39.70 | 40.30 | 7.7988 |
| 16 | Oxy, USA | Post Oak Blvd | 1880 | 10.30 | -80.00 | -45.70 | 34.30 | 30.0875 |
| | Oxy, USA | | 1880 | | | -41.30 | | |
| | Oxy, USA | | 1940 | | | -39.30 | | |
| 17 | Shell | Moss Hill | 1945 | 26.68 | -85.00 | -40.60 | 44.40 | 52.8681 |
| 18 | Shell | Huffman | 1885 | 26.68 | -85.00 | -40.60 | 44.40 | 51.2372 |
| 19 | Shell | Huffman | 1925 | 23.35 | -85.00 | -37.30 | 47.70 | 16.4062 |
| 20 | Shell | Pasedena | 1985 | 9.31 | -90.00 | -31.50 | 58.50 | 0.0892 |
| 21 | Shell | Cat. Springs | 1965 | 32.06 | -90.00 | -40.80 | 49.20 | 30.6881 |
| 22 | Shell | Katy | 1905 | 32.06 | -90.00 | -40.90 | 49.10 | 30.4440 |
| 23 | Shell | Katy | 1935 | 29.07 | -90.00 | -45.00 | 45.00 | 59.2560 |
| 24 | Shell | One Shell Pl. | 1875 | 29.07 | -90.00 | -45.00 | 45.00 | 57.4187 |
| 25 | Shell | One Shell Pl. | 1965 | 23.35 | -85.00 | -37.30 | 47.70 | 16.7471 |
| 26 | Shell | One Shell Pl. | 1875 | 9.31 | -90.00 | -31.30 | 58.70 | 0.0805 |
| 27 | Shell | One Shell Pl. | 1905 | 26.83 | -91.00 | -34.90 | 56.10 | 3.5602 |
| 28 | Shell | Alvin | 1945 | 26.83 | -91.00 | -38.90 | 52.10 | 9.1306 |
| 29 | Shell | Alvin | 1855 | 25.70 | -91.00 | -39.40 | 51.60 | 8.5874 |
| 30 | Shell | Alvin | 1965 | 29.49 | -91.00 | -36.70 | 54.30 | 7.3808 |
| 31 | Shell | Freeport | 1915 | 29.49 | -91.00 | -36.70 | 54.30 | 7.1930 |
| 32 | Shell | Pelican Is. | 1895 | 25.70 | -91.00 | -39.40 | 51.60 | 8.7725 |
| | Shell | Pelican Is. | 1935 | 19.00 | | | | |
| | Southern Pac. | Englewood | 1985 | 16.90 | | -43.90 | | |

# Table 1 - Houston Annual Outage Times (Continued)

HOUSTON OUTAGE TIME (sec/yr)

| M/W Receiver Number | | Station Address (Transmitter) | Carrier Freq (MHz) | Path Length (mi) | Rcvr Sens (dBm) | Receive Signal Lv (dBm) | Fade Margin (dB) | * Non-Diversty Annual Outage (sec) |
|---|---|---|---|---|---|---|---|---|
| | Southern Pac. | Strang | 1905 | 16.90 | | -43.90 | | |
| | Tenneco | | 1855 | 20.00 | | -37.40 | | |
| | Tenneco | | 1935 | 20.00 | | -37.40 | | |
| | Tenneco | | 1915 | 25.00 | | -36.50 | | |
| | Tenneco | | 1865 | 25.00 | | -36.50 | | |
| | Tenneco | | 1925 | 22.00 | | | | |
| | Tenneco | | 1875 | 20.00 | | -35.90 | | |
| | Tenneco | | 1955 | 20.00 | | -35.90 | | |
| | Transco | | 1895 | 30.00 | | -34.90 | | |
| | Transco | | 1915 | 35.60 | | -37.20 | | |
| 33 | Transco | Transco Tower | 1865 | 35.60 | -84.00 | -37.60 | 46.40 | 75.9881 |
| 34 | Transco | Dayton | 1895 | 29.50 | -82.30 | -34.90 | 47.40 | 34.8973 |
| 35 | Transco | Sour Lake | 1945 | 29.50 | -82.30 | -37.90 | 44.40 | 71.4665 |
| 36 | Transco | Rosenberg | 1855 | 19.50 | -85.80 | -35.10 | 50.70 | 4.6149 |
| 37 | Transco | Boling | 1935 | 19.50 | -85.80 | -38.10 | 47.70 | 9.6051 |
| | Trunkline Gas | | 1885 | 11.00 | | -45.20 | | |
| | Trunkline Gas | | 1945 | 11.00 | | -43.20 | | |
| | Trunkline Gas | | 1925 | 28.00 | | -45.40 | | |
| | Trunkline Gas | | 1975 | 28.00 | | -45.40 | | |
| | Trunkline Gas | | 1955 | 29.00 | | -45.50 | | |
| | Trunkline Gas | | 1895 | 29.00 | | -45.50 | | |
| | Trunkline Gas | | 1905 | 30.00 | | -47.10 | | |
| | UNOCAL | | 1955 | 16.00 | | -39.80 | | |
| | UNOCAL | | 1875 | 16.00 | | -39.80 | | |
| 38 | UNOCAL | 4635 SW F'wy | 1895 | 1.49 | -85.50 | -33.80 | 51.70 | 0.0017 |
| 39 | UNOCAL | Phoenix Tower | 1955 | 1.49 | -85.50 | -30.80 | 54.70 | 0.0009 |
| | UNOCAL | | 1965 | 1.00 | | | | |
| | Union Carbide | | 1865 | 25.00 | | | | |
| | Union Carbide | | 1855 | 21.00 | | -46.90 | | |
| | Union Carbide | | 1975 | 21.00 | | -46.90 | | |
| | Union Carbide | | 1945 | 24.00 | | | | |
| 40 | UnionPac RR | Spring | 1935 | 2.21 | -84.00 | -34.76 | 49.24 | 0.0098 |
| 41 | UnionPac RR | Spring Statio | 1855 | 2.21 | -84.00 | -35.13 | 48.87 | 0.0102 |
| 42 | UnionPac RR | Spring Statio | 1885 | 15.85 | -84.00 | -40.87 | 43.13 | 14.3918 |
| 43 | UnionPac RR | Conroe | 1965 | 15.85 | -84.00 | -40.51 | 43.49 | 13.8092 |
| | Valero Comm. | Allen III | 1855 | | -90.00 | -40.90 | 49.10 | |
| | Valero Comm. | Conoco | 1975 | | -90.00 | -31.90 | 58.10 | |
| 44 | Valero Comm. | Conoco | 1985 | 28.00 | -90.00 | -39.90 | 50.10 | 16.7862 |
| 45 | Valero Comm. | Katy | 1925 | 28.00 | -90.00 | -39.90 | 50.10 | 16.2788 |
| | Valero Comm. | Katy | 1935 | | -90.00 | -35.80 | 54.20 | |
| | Valero Comm. | Katy | 1915 | | -91.00 | -42.40 | 48.60 | |
| | Valero Comm. | Orchard | 1965 | | -91.00 | -42.40 | 48.60 | |
| 46 | Valero Comm. | Orchard | 1975 | 21.00 | -91.00 | -45.90 | 45.10 | 22.2814 |
| 47 | Valero Comm. | Boling | 1865 | 21.00 | -91.00 | -45.90 | 45.10 | 21.0404 |
| | Averages .................. | | 1920 | 19.01 | -85.02 | -40.10 | 46.41 | 25.6210 |

* Outage = Undp * 8760 hrs/yr * 3600 sec/hr
= a * b * 2.5 * 10E-6 * f/1000 * D * D * D * 10E(-F/10) * 8760 * 3600

where a = Terrain Factor = 1 for average terrain, with some roughness
b = Humidity Factor = 1/2 for Gulf Coast or similar hot, humid areas
f = frequency (MHz)
D = path length (mi)
F = Fade Margin (dB)

* From "Engineering Considerations for Microwave Communications Systems", (AG Communications Systems, 1989)

To arrive at a target reliability figure, let us assume that the average 2 GHz path in the United States transmits at a frequency of 1.92 GHz, is 17.1 miles in length[10] and that a fade margin of 35 dB is employed "...for typical use in the specified band [1.9 or 2.1 GHz], considering path reliability."[11]. Employing the outage probability formula of Barnett and Vagnats, we find:

$$\begin{aligned} U_{ndp} &= a \times b \times 2.5 \times 10^{-6} \times f \times D^3 \times 10^{-F/10} \\ &= 1 \times 1/4 \times 2.5 \times 10^{-6} \times 1.92 \times (17.1)^3 \times 10^{-35/10} \\ &= 0.000002 \end{aligned}$$

where

- $a =$ 1 = average terrain factor
- $b =$ 1/4 = temperate humidity factor
- $f =$ 1.92 GHz
- $D =$ 17.1 mi = Average Path Length
- $F =$ 35 dB = Typical Fade Margin

This equates to an outage time of 1 minute per year. One standard used by the microwave industry specifies 99.999% availability per hop, which is equivalent to $U_{ndp} = 0.00001$, or 315 seconds per year. Therefore, it appears that *the average microwave hop is over-engineered by a factor of 315/60 ≐ 5, or 7* ***dB***.

In specific instances, this over-engineering is much more pronounced. For example, in the Houston area, Shell has a 9.3 mile link running between downtown Houston and Pasadena which has a fade margin of 58.5 dB (see Table 1). This corresponds to $U_{ndp} = 0.000000003$, or 0.09 seconds per year! This corresponds to an over-design of *more than 35 dB*. The reliability of microwave systems in the Houston area is over-engineered on average by over 11 dB when compared to the industry standard of 99.999% availability per hop.

### 1.2.2 Diversity Can Greatly Improve Microwave Reliability

Antenna diversity techniques, such as space, angle and frequency diversity, can further improve microwave system reliability. The improvement factors resulting from implementation of these techniques are quite significant, and are discussed below.

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10 According to a survey completed by the UTC on usage of the 1.8 GHz band in 1990. See footnote 15.

11 "Telecommunications Systems Bulletin 10-E, Rev. D", Telecommunications Industry Association, August 3, 1992, p.28.

1.2.2.1 *Space Diversity*

Space diversity, when properly employed, is one solution which can improve PCN-microwave coexistence potential and still maintain the ultra-high reliability levels found in Houston.

Vignats[12] has defined as part of his work a "space diversity improvement factor"[13]. This factor quantifies reliability improvement in terms of antenna spacing, path length, frequency and fade margin as follows[14]:

$$I_{sd} = (7 \times 10^{-5} \times f \times s^2 \times 10^{Fs/10})/D$$

where

| | | |
|---|---|---|
| $I_{sd}$ | = | Space Diversity Improvement Factor *($10 \leq I_{sd} \leq 200$)* |
| f | = | Frequency, in GHz |
| s | = | Antenna Separation, in feet *($30 \leq s \leq 50$)* |
| Fs | = | Fade margin associated with the second antenna, in dB *($20 \leq Fs \leq 50$)* |
| D | = | Path Length, in miles |

At 2 Ghz, excellent diversity will be obtained with minimum vertical spacing of 40 feet. Table 2 and Figure 2 illustrate space diversity improvement with respect to fade margin, assuming 30, 40 and 50 foot vertical spacings, the average path length in Houston (19 mi), and the average transmit frequency (1920 MHz).

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[12] It is important to note that the space diversity improvement factors developed by Vignats are quite conservative. Findings in some Japanese studies have indicated an improvement over 10 times better than stated below.

[13] Engineering Considerations for Microwave Communications Systems. AG Communication Systems, 1989, p.61.

[14] Vignats, A. "Space Diversity Engineering", *The Bell System Technical Journal*, Vol. 54, No. 1, January, 1975.

**Table 2 - Space Diversity Improvement Factor**

| Path Length (mi) | Freq (GHz) | Antenna Spacing (ft) | Fade Margin (dB) | $I_{sd}$ (dB) | $I_{sd}$ |
|---|---|---|---|---|---|
| 19 | 1.92 | 30 | 20 | 10 | 10 |
| 19 | 1.92 | 30 | 25 | 10 | 10 |
| 19 | 1.92 | 30 | 30 | 10 | 10 |
| 19 | 1.92 | 30 | 35 | 13 | 20 |
| 19 | 1.92 | 30 | 40 | 18 | 64 |
| 19 | 1.92 | 30 | 45 | 23 | 200 |
| 19 | 1.92 | 30 | 50 | 23 | 200 |
| 19 | 1.92 | 40 | 20 | 10 | 10 |
| 19 | 1.92 | 40 | 25 | 10 | 10 |
| 19 | 1.92 | 40 | 30 | 10 | 11 |
| 19 | 1.92 | 40 | 35 | 16 | 36 |
| 19 | 1.92 | 40 | 40 | 21 | 113 |
| 19 | 1.92 | 40 | 45 | 23 | 200 |
| 19 | 1.92 | 40 | 50 | 23 | 200 |
| 19 | 1.92 | 50 | 20 | 10 | 10 |
| 19 | 1.92 | 50 | 25 | 10 | 10 |
| 19 | 1.92 | 50 | 30 | 13 | 18 |
| 19 | 1.92 | 50 | 35 | 17 | 56 |
| 19 | 1.92 | 50 | 40 | 22 | 177 |
| 19 | 1.92 | 50 | 45 | 23 | 200 |
| 19 | 1.92 | 50 | 50 | 23 | 200 |

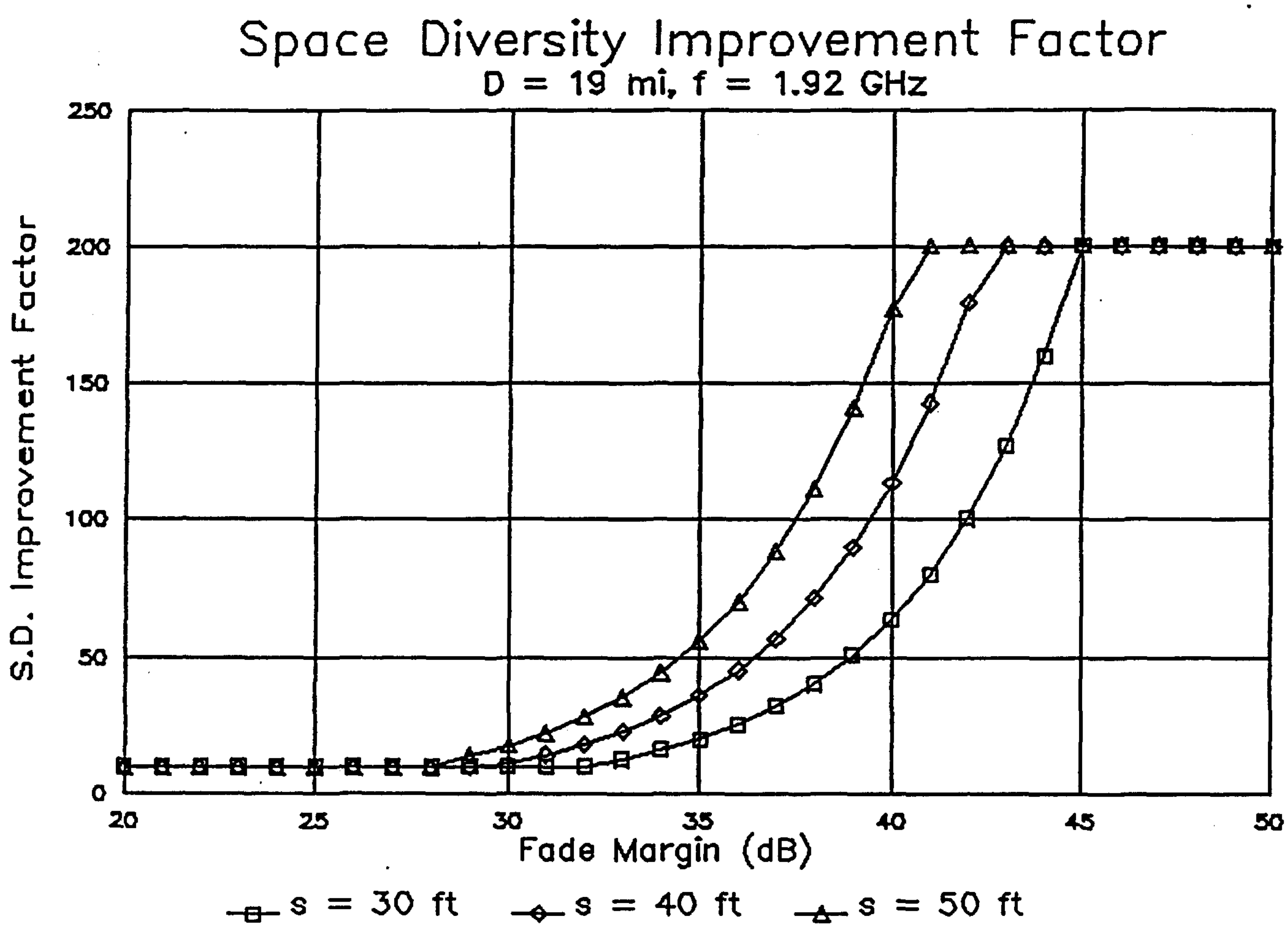


Figure 2 - Space Diversity Improvement Factor vs Fade Margin